measurements are available to calibrate the models.

A comparison (Fig. 1) of that earlier result with Brandt and colleagues' findings in the western Sahel, for example, shows that the previous study tended to underestimate the number of trees in the drier regions (areas with annual rainfall of less than 600 millimetres). Moreover, the previous estimates provided no information on the location and size of individual trees within each square kilometre, whereas Brandt and colleagues provide detailed information on the location and size of every individual canopy. The improvement provided in the latest study can also be seen in the much higher level of detail it gives for the wetter regions (those with annual rainfall greater than 600 mm), and shows local spatial variability in trees that is presumably associated with contrasting soil types, water availability, land use and land-use history.

There are, of course, caveats and limitations to Brandt and colleagues' work and the potential for scaling up their approach to a global analysis. Successful canopy detection declined drastically below a canopy diameter of 2 m, owing to constraints imposed by the spatial resolution of the imagery, and consistent with earlier work[3]. Although we can expect further improvements in the spatial resolution of satellite images, it becomes pertinent to ask what minimum canopy size is needed to characterize woody-plant communities in various regions. For global tree-canopy mapping, if we assume that the computational and storage challenges associated with large data volumes can be overcome, the biggest roadblock would lie in developing efficient approaches for automated classification and delineation of canopies. Brandt and colleagues' deep-learning method required an input of approximately 90,000 manually digitized training points. This approach becomes untenable for work on a global scale, and more-automated (unsupervised) methods for extracting information from satellite imagery would be necessary[4].

A related problem is the ability to distinguish between what might look like one large canopy and adjacent, overlapping canopies of different individual trees. To improve canopy separation, Brandt *et al.* used a weighting scheme in training their convolutional neural network, but still resorted to a 'canopy clump' class to describe aggregated canopy areas of more than 200 m^2, suggesting that the separation approach was not always effective. For application in wetter regions, where overlapping canopies in woodlands and forests are common, canopy delineation and separation methods will need refinement and automation to be feasible at global scales.

Yet more challenging is the identification of tree species. Although feasible, on the basis of canopy colour, shape and texture[5], it will be particularly tricky at regional and global scales and across biodiverse ecosystems. The mapping of individual tree canopies by species will probably remain at the top of the Earth-observation research community's wish list for some time[6].

> "Never before have trees been mapped at this level of detail across such a large area."

In the years ahead, remote sensing will undoubtedly provide unprecedented detail about vegetation structure as data from a range of sources – including light detection and ranging (lidar), radar and high-resolution visible and near-infrared sensors – become more readily available[7]. Satellite-derived high-resolution data on tree canopy size and density could contribute to the inventory and management of forests and woodland, deforestation monitoring, and assessment of the carbon sequestered in biomass, timber, fuel wood and tree crops. The ability to map the size and location of individual tree canopies using such satellite data will complement information available from other instruments that provide data for tree height, vertical canopy profiles and above-ground wood biomass. Continuing research will be needed to develop more-efficient canopy-classification algorithms. In the meantime, Brandt and colleagues have clearly demonstrated the potential for future global mapping of tree canopies at submetre scales.

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1. Brandt, M. *et al. Nature* **587**, 78–82 (2020).
2. Crowther, T. W. *et al. Nature* **525**, 201–205 (2015).
3. Axelsson, C. R. & Hanan, N. P. *Biogeosciences* **14**, 3239–3252 (2017).
4. Reichstein, M. *et al. Nature* **566**, 195–204 (2019).
5. Engler, R. *et al. Forest Ecol. Mgmt* **310**, 64–73 (2013).
6. Draper, F. C. *et al. Trends Ecol. Evol.* https://doi.org/10.1016/j.tree.2020.08.003 (2020).
7. National Academies of Sciences, Engineering, and Medicine. *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space* (Natl Academies Press, 2018).

Astronomy

A fast radio burst in our own Galaxy

Amanda Weltman & Anthony Walters

The origins of millisecond-long bursts of radio emissions, known as fast radio bursts, from beyond our Galaxy have been enigmatic. The detection of one such burst from a Galactic source helps to constrain the theories. **See p.54, p.59 & p.63**

Sometimes, being an astrophysicist is an exercise in international detective work. Piecing together the evidence is complicated, because observations are often made after a key event, the experiments are not generally repeatable and, when it comes to telescopes, it is all about location, location, location. Three papers[1–3] in this issue of *Nature* report exactly this situation in the detection of a phenomenon called a fast radio burst (FRB) coming from a source in our Galaxy. Intriguingly, the FRB was accompanied by a burst of X-rays[4–6]. The discovery was made and understood by piecing together observations from multiple space- and ground-based telescopes, and should help us to work out the mechanisms that drive these spectacular events.

The name 'fast radio bursts' is a good description of what they are: bright bursts of radio waves with durations roughly at the millisecond scale. First discovered[7] in 2007, their short-lived nature makes it particularly challenging to detect them and to determine their position on the sky. The smorgasbord of theories[8] that has been proposed to explain FRBs has, until recently, outpaced our discovery of actual FRB events. The majority of these theories invoke some kinds of stellar remnant as FRB sources. In particular, highly magnetized young neutron stars known as magnetars have

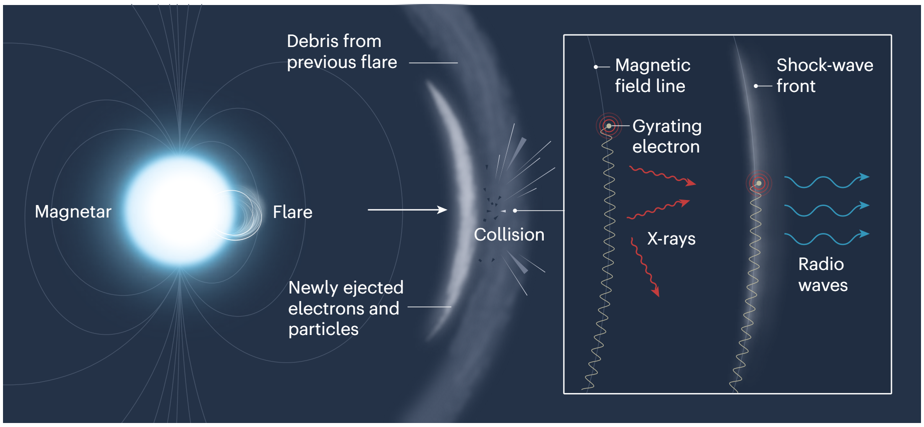

Figure 1 | A potential mechanism for the formation of fast radio bursts. A bright, millisecond-long burst of radio waves, known as a fast radio burst (FRB), has been detected[1–3] coming from a highly magnetized stellar remnant (a magnetar) in our Galaxy. The radio waves were accompanied by X-ray emissions[4–6]. One possible mechanism[9,10] for the formation of such an FRB is that the magnetar produces a submillisecond-long flare of electrons and other charged particles, which collides with particles that had been emitted from previous flares (note that the collision occurs a great distance away from the magnetar; this distance is not shown to scale). The collision generates an outward-moving shock front, which in turn produces huge magnetic fields. Electrons gyrate around the magnetic field lines, and thereby emit a burst of radio waves. The shock wave also heats the electrons, which causes them to emit X-rays.

emerged as leading candidates, because their strong magnetic fields could act as 'engines' that drive FRBs.

A key approach to testing these progenitor theories is to associate FRBs with other astronomical phenomena. It is therefore crucial to narrow down the potential positions of FRBs to small regions of the sky, so that the associations are unambiguous. Until now, however, there has been no observational evidence directly linking FRBs with magnetars. The detection reported in the three new papers offers the first such evidence, thereby providing vital clues that will help us understand the origins of at least some FRBs.

The timeline for the observations of these results is as follows. On 27 April 2020, two space observatories – the Neil Gehrels Swift Observatory and the Fermi Gamma-ray Space Telescope – detected multiple bursts of X-ray/γ-ray emissions coming from the Galactic magnetar SGR 1935+2154. On the following day, the same region of the sky was in view of ground-based telescopes in the Western Hemisphere. Two radio telescopes – the Canadian Hydrogen Intensity Mapping Experiment (CHIME) and the Survey for Transient Astronomical Radio Emission 2 (STARE2), in the United States – detected an FRB from that sky region. The FRB has since been named FRB 200428.

The CHIME team was the first to announce the detection, and it loosely localized the event to a region that contains SGR 1935+2154 – thereby hinting at the exciting first association of an FRB with a known Galactic source. These findings are reported[1] by the CHIME/FRB Collaboration on page 54. The announcement prompted the STARE2 scientists to check their own data, and to confirm the discovery of FRB 200428; these findings are described by Bochenek *et al.*[2] on page 59. However, Bochenek and colleagues found the FRB to be about 1,000 times brighter than had been announced by the CHIME/FRB Collaboration. This discrepancy was resolved after the CHIME/FRB Collaboration recalibrated its data, whereupon it found the brightness to be the same as that determined by Bochenek and co-workers[1,2].

In addition, several space telescopes and detectors reported an X-ray burst coming from SGR 1935+2154 at the same time as FRB 200428. These included the European Space Agency's INTEGRAL space telescope[4], Russia's Konus detector aboard NASA's Wind spacecraft[5], and the Chinese Insight space observatory[6].

Later that day, the sky region of interest came into view of the extremely sensitive Five-hundred-meter Aperture Spherical Radio Telescope (FAST) located in China, which had been observing SGR 1935+2154 in the previous weeks. As reported by Lin *et al.*[3] on page 63, FAST did not detect any FRB activity coming from SGR 1935+2154, even though the Fermi Gamma-ray Space Telescope detected multiple X-ray bursts during that time. However, two days later, FAST detected an FRB at the same location as FRB 200428, and localized the event to a small region around SGR 1935+2154. Each of the experiments described above thus played a part in the detection of FRB 200428, the measurement of its brightness, and the association of the FRB with SGR 1935+2154.

FRB 200428 is the first FRB for which emissions other than radio waves have been detected, the first to be found in the Milky Way, and the first to be associated with a magnetar. It is also the brightest radio burst from a Galactic magnetar that has been measured so far – which potentially solves a key puzzle in this field. Before the discovery of FRB 200428, the absence of X-ray and γ-ray bursts from repeating FRBs lent weight to certain magnetar theories of the origins of FRBs. But because no bright radio bursts had been observed coming from Galactic magnetars, it seemed unlikely that magnetars could be FRB sources at all. The discovery of FRB 200428 proves that magnetars can indeed drive FRBs. Moreover, FRB 200428 is the first Galactic radio burst that is as bright as the FRBs observed in other, nearby galaxies, which also provides much-needed evidence that magnetars could be the sources of extragalactic FRBs.

Intriguingly, there are several mechanisms by which magnetars can drive FRBs, each of which has a distinct observational signature. The new results thus open up a host of exciting problems to explore. For example, what theoretical mechanism could give rise to such bright, yet rare, radio bursts with X-ray counterparts? One promising possibility is that a flare from a magnetar collides with the surrounding medium and thereby generates a shock wave[9,10] (Fig. 1). Observations of nearby rapidly star-forming galaxies will be crucial for finding events similar to FRB 200428, to help pin down the actual mechanism.

Other magnetar-driven FRB mechanisms would produce accompanying neutrino bursts[11]. There is therefore scope for truly multi-messenger astronomy – the coordinated use of fundamentally different signal types, such as electromagnetic radiation and neutrinos – to provide another key clue to this cosmic mystery. Moreover, the discovery highlights the need for international scientific cooperation in astronomy, and for sky coverage from multiple locations.

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1. The CHIME/FRB Collaboration. *Nature* **587**, 54–58 (2020).
2. Bochenek, C. D. *et al. Nature* **587**, 59–62 (2020).
3. Lin, L. *et al. Nature* **587**, 63–65 (2020).
4. Mereghetti, S. *et al. Astron. Telegram* 13685 (2020).
5. Ridnaia, A. *et al. Astron. Telegram* 13688 (2020).
6. Zhang, S. N. *et al. Astron. Telegram* 13696 (2020).
7. Lorimer, D. R., Bailes, M., McLaughlin, M. A., Narkevic, J. & Crawford, F. *Science* **318**, 777–780 (2007).
8. Platts, E. *et al. Phys. Rep.* **821**, 1–27 (2019).
9. Beloborodov, A. M. *Astrophys. J.* **843**, L26 (2017).
10. Metzger, B. D. *et al. Mon. Not. R. Astron. Soc.* **485** 4091–4106 (2019).
11. Metzger, B. D., Fang, K. & Margalit, B. Preprint at https://arxiv.org/abs/2008.12318 (2020).